AFHRL-TR-77-29

AIR FORCE HUMAN RESOURCES LABORATORY

AD A043649

EFFECTS OF SIMULATOR TRAINING AND PLATFORM MOTION ON AIR-TO-SURFACE WEAPONS DELIVERY TRAINING

By

Thomas H. Gray

Robert R. Fuller, Major, USAF

FLYING TRAINING DIVISION

Williams Air Force Base, Arizona 85224

July 1977

Final Report, for Period August 1976 – March 1977

AIR FORCE SYSTEMS COMMAND

BROOKS AIR FORCE BASE, TEXAS 78235

NOTICE

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.

This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DoDD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

EDWARD E. EDDOWES, Technical Adviser
Flying Training Division

DAN D. FULGHAM, Colonel, USAF
Commander

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFHRL-TR-77-29
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): EFFECTS OF SIMULATOR TRAINING AND PLATFORM MOTION ON AIR-TO-SURFACE WEAPONS DELIVERY TRAINING

5. TYPE OF REPORT & PERIOD COVERED: Final, August 1976 - March 1977

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Thomas H. Gray, Robert R. Fuller

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62205F, 11230327

11. CONTROLLING OFFICE NAME AND ADDRESS: HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235

12. REPORT DATE: July 1977

13. NUMBER OF PAGES: 50

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

air-to-surface
application of training technology
flying training research
pilot training
platform motion
simulation
student pilot ability
transfer of training

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives of this research were to determine: (a) the extent to which generalized, conventional, air-to-surface (A/S) weapons delivery training in the Advanced Simulator for Pilot Training (ASPT) transferred to a specific aircraft; (b) the contribution of six-degree-of-freedom platform motion to the transfer of training from simulator to aircraft; and (c) the differential effects, if any, of this simulator training on student pilots of differing ability levels. These objectives were accomplished by selecting 24 students in the lead-in A/S training course at Holloman AFB, NM, to serve as subjects. These subjects progressed through lead-in training, receiving all training except the A/S flights, and then proceeded to Williams AFB where they were assigned into matched experimental and control groups. At Williams AFB, AZ, all of the subjects received academic training in weapons delivery

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Item 20 (Continued):

techniques and procedural training on F-5B operations. At this point, the students in the control groups flew two data collection sorties in the F-5B aircraft, performing 10°, 15°, and 30°, bomb deliveries. The experimental groups received A/S weapons delivery training in ASPT on 10°, 15°, and 30° bomb deliveries with a fixed number of trials on each event. The experimental subjects then received two data collection flights in the F-5B identical to those received by the control group. Analysis of the results proved that simulator training significantly increased air-to-surface weapons delivery skills (e.g., approximately double the number of qualifying bombs, a one-fourth reduction in circular error) but that platform motion was not a contributing factor in this process. It was also found that novice student pilots of greater initial ability benefit most from such simulator training when a minimum fixed number of trials is used.

PREFACE

This effort was conducted by the Flying Training Division of the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona, and supported by the 425th Tactical Fighter Training Squadron, Williams Air Force Base, Arizona. The project was completed under project 1123, Flying Training Development; task 112303, The Exploitation of Simulation in Flight Training; and work unit 11230327, Contribution of Simulator Platform Motion in Air-to-Surface Weapons Delivery Training. Mr. J. F. Smith was the Project Monitor and Task Scientist. The authors would like to extend special thanks to Captains Raymond P. Seymour (425th TFTS), Setephan G. Henrich (465th TFTS), and Byron E. Hukee (425th TFTS) for their dedication as instructor pilots for the duration of the study. Appreciation is also expressed for the statistical analyses performed by Mr. Tien F. Sun. This technical report covers research performed between September and November 1976.

TABLE OF CONTENTS

PRECEDING PAGE BLANK-NOT FILMED

LIST OF TABLES

EFFECTS OF SIMULATOR TRAINING AND PLATFORM MOTION ON AIR-TO-SURFACE WEAPONS DELIVERY TRAINING

I. INTRODUCTION

The air-to-surface mission is a major role for the Tactical Air Command (TAC). Specialized aircraft are being procured to support this operational requirement; and, as occurs with the acquisition of all weapons systems, new procedures and equipment must be developed to train personnel for their effective utilization. As regards both of these items, the greatest amount of resources will be expended initially in providing simulation capabilities for pilot training. It is, therefore, of critical importance that the simulator deliver the cues essential to this training and that the training itself be highly efficacious. The research reported in this study deals with air-to-surface simulation training transfer and motion cueing effects in general, and it represents a first step towards achieving these objectives.

Background and Literature Review

The foregoing summarized the reasons for, and purposes of the study, but a brief expansion of these points will add some clarifying details.

Backgr l. The Air Force plans extensive simulator procurements in order to reduce flying training hours while maintaining operational readiness. In light of this fact, it is highly desirable to determine the effectiveness of candidate simulator configurations for specific training applications prior to their acquisition by the user. From the user's viewpoint, there are two aspects to this process. First, the simulation must provide the cues essential for training; and second, there must be positive training transfer from the simulator to the aircraft. From a budgetary standpoint, these two requirements are valid, but the cost element must be considered as well. Unnecessary features should not be purchased: the simulation must not only be effective, but also it must be efficient.

One expensive flight simulator feature, of which the universal essentiality is not certain, is platform motion. The question as to whether the existence of simulator platform motion enhances the training effectiveness of the device is an issue of considerable importance. Using a moving platform to provide vestibular and kinesthetic cues to the pilot is a costly process. Not only are initial expenses increased, but life-cycle costs are also inflated. Unless some positive training value can be demonstrated for the presence of motion, cost-avoidance considerations must force its exclusion from the simulator.

The Air Force Human Resources Laboratory (AFHRL) has completed several studies which addressed the value of motion cueing to the training effectiveness of flight simulators. These studies have provided estimates of the contribution of simulator motion in transfer of training to the aircraft; however, due to the lack of visual scene capabilities for air-to-surface weapons delivery simulator training, they addressed only the learning of aircraft instrument and transition skills and did not address maneuvers involving high "G"-low altitude tasks.

AFHRL recently participated in a study (ASD Project 2235) which facilitated the development of a visual scene capability on the Advanced Simulator for Pilot Training that included a conventional air-to-surface weapons delivery complex and the display of tactical targets for more advanced operational training. This visual capability, when combined with objective scoring strategies and the existing motion system permitted the investigation of the transfer-of-training phenomena described in the present study.

Air-to-surface weapons delivery is a high risk area of training for newly rated pilots. Large Air Force expenditures for simulation of this activity are imminent. Therefore, a determination of both the feasibility of simulator training in this area and an assessment of the contribution of platform motion to simulator effectiveness in this context was deemed essential.

Literature Review. There have been numerous studies investigating the effects of platform motion upon piloting tasks. Many of these have been directed toward determining the degees of freedom required for motion systems in particular settings, as well as what levels of fidelity are needed (Bergeron, 1970; Jacobs, WillIges, & Roscoe, 1973). This body of research, however, is equivocal, and findings have not always been consistent from study to study.

Certain studies have shown that motion produces improved pilot performance in controlling the simulator (Borlace, 1967; Brown, Johnson, & Mungall, 1960). In this vein, Rathert, Creer, and Sadoff (1961) demonstrated that varying the fidelity of motion cueing directly affected the pilot's performance in the simulator. Koonce (1974) investigated the training effectiveness of platform motion using three conditions of motion cueing (i.e., no motion, sustained motion cueing, and washout motion cueing). This study reported an increase in pilot performance in the simulator when *either* condition of motion cueing was present.

From Koonce's study, it is seen that the evidence supporting the positive effects of high fidelity motion cueing is not firmly established. Demaree, Norman, and Matheny (1965) concluded that in many instances the level of fidelity could be reduced without any appreciable performance decrement on tracking tasks. Huddleston (1966) reported that motion may not be necessary for those piloting tasks performed in the more stable flight regimes, although it may be beneficial in highly dynamic regimes. Finally, a follow-on study to Koonce (Jacobs & Roscoe, 1975) may have revealed a critical facet of the issue. It was found that pilot performance, in terms of errors committed, improved in the simulator with the presence of either *normal* washout motion or *random* washout motion where the latter condition provided appropriate onset cueing, but random directional cueing. Perhaps it may be that motion serves only to alert the pilot to a change in conditions and rarely has any intrinsic stimulus value beyond this point (Irish, Grunzke, Gray, & Waters, 1977). Simple "movement," not complexly driven motion platforms, may provide a sufficient condition for simulation.

A plethora of studies attest to the training value of simulation (Caro, 1970; Prophet, Caro, & Hall, 1972; Reid & Cyrus, 1974; Woodruff & Smith, 1974). But the effectiveness of simulator training varies enormously when viewed across specific applications, and it is wise to pretest whenever possible. In addition, individual differences in the student population may produce widely different effects of such training. The present study was designed to investigate these possibilities as well as provide baseline data for envisioned air-to-surface simulator training programs

Problem Statement

At the present time, TAC air-to-surface training is taught in tactical aircraft. This procedure constitutes a dangerous activity for newly rated pilots. An alternative, if demonstrated to be effective, is the use of flight simulators designed with air-to-surface capabilities. A related issue is the efficiency of this training for student pilots of differing ability levels. Is the payoff of simulator training relatively equal for all students, or do some profit to a greater extent than others? Finally, if it were shown that simulator platform motion does not increase the training transfer to the aircraft, significant reductions in the life-cycle costs of the device would be realized.

Objectives

The objectives of this research were to determine: (a) the extent to which generalized, conventional, air-to-surface weapons delivery training in the Advanced Simulator for Pilot Training transfers to a specific aircraft; (b) the contribution of six-degree-of-freedom platform motion to the transfer of training from simulator to aircraft; and (c) the differential effects, if any, of this simulator training on student pilots of differing ability levels.

Study Rationale

The main theme followed throughout the study was that the approach should be intensely realistic in terms of Air Force operations. Accordingly, it was decided to select a homogenous group of inexperienced pilots who had already been identified for fighter training, train them on specified tasks in the simulator, then measure their performance on the same tasks in an aircraft on an actual gunnery range. The result was a simple study, easily and quickly understood, that produced information directly applicable to Air Force areas of concern.

A major decision made in establishing the simulator configuration dealt with the G-Seat. The G-Seat can serve as a platform motion surrogate by providing vestibular and kinesthetic cues. If the G-Seat had been included as an independent variable, two additional groups of subjects would have been required for the experiment. This action would have increased the size and duration of the effort by two-thirds. Due to the urgent demand for immediate information on platform motion effects, a larger study was not a viable option. Consequently, it was decided that the G-Seat would be a fixed study factor.

The fully operative motion condition was chosen for the G-Seat configuration. The reason for this selection was that, unlike motion

platforms, the inclusion of a G-Seat adds very little to either the acquisition or life-cycle costs of a flight simulator. Since it seemed highly probable that all future sophisticated flight simulators would be procured with G-Seats, it was believed that the study results would have greater validity if the G-Seat were operative during the simulator training phase.

The aircraft selected for the data flights was the F-5B, primarily because F-5B training is accomplished at Williams Air Force Base, Arizona, and the proximity of instructor pilots and aircraft greatly simplified this portion of the data collection. An additional reason for its selection was because it is a two-seat aircraft and two data collection flights per subject could be scheduled with very little checkout time in the aircraft, since an instructor would be on board to perform all tasks not required as part of the study (as well as providing adequate flight safety). Had the F-5B not been used, it would have been necessary to conduct the study as part of a formal combat crew training (CCT) program where the subjects would have received a complete checkout in the CCT aircraft. This might have caused safety problems due to dissimilar flight characteristics between the aircraft and the simulator. These problems were avoided by using the F-5B. This point will be discussed further in the Methods and Procedures section.

Gaining support for this project was greatly facilitated because of its "training/research" aspect. Not only would important research issues be examined, but valuable training would be gained by the participants. Air-to-surface training has always represented one of the most difficult areas to train in the aircraft. A chance to obtain some pretraining for students prior to their arrival at CCT was readily endorsed by the training squadrons.

II. METHOD AND PROCEDURES

As stated in the rationale, a major objective of the approach was that the study be performed within the context of typical Air Force training operations. This requirement was the determining factor in the study's methodology.

Subjects

The personnel who serve as subjects in simulation research are usually found to be the major single source of variance when the analysis of the experimental results is completed. In this study, great care was taken to remove as much of this unwanted variance as possible through the use of judicious selection techniques and counterbalancing.

Subject Background and Selection. It was decided that the most representative source of subjects would be recent undergraduate pilot training (UPT) graduates who had been identified for fighter assignments. These novice pilots receive a short 6-week fighter lead-in training course at Holloman Air Force Base, New Mexico, after graduation from UPT and prior to their arrival at CCT for their respective aircraft. The lead-in course is designed to improve formation flying skills and to provide an introduction to high performance maneuvering and to air-to-ground weapons delivery. At the time of this study, the course contained 19 sorties in the two-place T-38 aircraft, the same aircraft flown in UPT.

The subjects were given the entire lead-in training course with the exception of the air-to-surface indoctrination. This required deleting two T-38 sorties which were replaced by two sorties in the F-5B at Williams Air Force Base, Arizona, as part of the study. The two sorties deleted at Holloman Air Force Base are flown "dry" since the T-38 does not have the capability to deliver ordnance, whereas the two F-5B sorties gave the subjects the opportunity to drop 12 BDU-33 practice bombs which would serve as criterion measures.

Actual selection of the subjects required several steps. First, the Air Force Military Personnel Center pipeline management section provided a list of potential subjects who had enough time available between lead-in training and their CCT reporting dates to allow a 2-week tour of duty for this study. From this list, only those with no prior Air Force service time or significant fixed-wing flying experience other than UPT were selected for possible participation in the study. Finally, the actual subjects were randomly selected from this reduced list and their names sent to the training squadron at Hollman AFB. At this point the training squadron developed a rank-ordering of the subjects. This rank-ordering was made on the basis of the students' performance during lead-in training.

Subject Assignment. Upon the completion of lead-in training, the student pilots were sent to Williams AFB in groups of six. It was necessary to use four lead-in training classes in order to produce a total N of 24 students, eight subjects assigned to each of three groups.

The rankings given by the squadron at Holloman AFB formed the basis for assigning each subject into either a control group which would receive no simulator training, or one of two experimental groups (subdivided into motion and no-motion groups). For the first class, the subjects ranked 1 and 6 were placed in the motion group, 2 and 5 in the no-motion group, and 3 and 4 in the control group. Class two grouped students 2 and 5 into the motion condition, 3 and 4 into the no-motion condition and 1 and 6 were used as controls. Class three used the last available combination and class four used the first combination over again. Fortunately, this counterbalancing on student performance also produced groups that were well equated from the standpoint of mean fixed-wing time. The control group averaged 259 hours, the motion experimental group averaged 276 hours, and the no-motion experimental group averaged 248 hours. These minor differences were not statistically significant at the five percent level of confidence.

It is believed that this procedure accomplished its purposes: namely, subject groups matched as to ability, and a study that would allow valid generalizations on the benefits of air-to-surface simulator training to the appropriate Air Force population.

Instructor Pilots

With one exception, the study's instructor pilots were drawn from the 425th Tactical Fighter Training Squadron stationed at Williams AFB. All Instructor Pilots were highly experienced in air-to-surface weapons delivery and were thoroughly briefed on the purposes of the study and their jobs within it. Special training on the ASPT console operation and advanced training features capabilities was given to the Instructor Pilots who administered the simulator training.

Apparatus

The apparatus used in the study consisted of two devices: the Advanced Simulator for Pilot Training (ASPT), and the F-5B aircraft.

ASPT. The ASPT located at the Air Force Human Resources Laboratory/Flying Training Division (AFHRL/FT) was used for the training portion of the study. Technical references for this device are found in Hagin and Smith (1974); and Rust (1975), but a short description will be given.

ASPT has two fully instrumented T-37 cockpits mounted upon six-degree-of-freedom motion platforms. The synergistic motion system has six active drive legs with approximately 5 feet of vertical travel and 4 feet of horizontal travel. Displacement capabilities include: pitch −20 degrees to +30 degrees; roll ±22 degrees; and yaw ±32 degrees. These displacements are intended to provide initial (onset) cues for all maneuvers. The 31-bellow pneumatic G-seat in ASPT is designed to provide more continuous cues than the motion platform and accomplishes this by the orderly inflation and deflation of the bellows in response to the requirements of each particular maneuver.

The visual system of ASPT is comprised of seven 36-inch monochromatic cathode-ray tubes placed around the cockpit giving the pilot +110 degrees to −40 degrees vertical cueing and ±150 degrees of horizontal cueing. The computer-generated visual scene has the capability to display information for most pertinent ground references (mountains, runways, hangars, etc.) within a 100-square-nautical-mile area of Williams AFB. The configuration for this study included the conventional gunnery range visual data base developed for project 2235 and the depressible bombing sight (A-37 Optical Sight Unit) installed for that project (Hutton, Burke, Englehart, Wilson, Rumaglia, & Schneider, 1976).

The aerodynamic mathematical models driving the simulator are those of the T-37 aircraft. The feasibility of changing these models to increase the performance of the simulator to more representative airspeeds and handling qualities of fighter-type aircraft was investigated. Estimates of that effort placed unacceptable time delays on the project which would have not allowed information to be provided to the using command within the required time frame.

F-5B. The F-5B proved to be an excellent choice as the criterion test vehicle for measuring the ability of the subjects to perform air-to-surface weapons delivery. As mentioned previously, the flight characteristics of the F-5B are similar to those of the T-38 aircraft which the subjects had flown for approximately 110 hours in UPT and another 20 hours during lead-in training. Differences in operational procedures and "switchology" were prebriefed prior to each aircraft mission and presented no problems during the data collection flights.

Independent Variables

Four independent variables were used in the study. The first of these, training conditions, represents the weapons delivery training received by the subjects at Williams AFB. There were three levels of this variable: no simulator training (Control Group); simulator training with platform motion (Experimental Group 1); and, simulator training without platform motion (Experimental Group 2). The specific syllabus content and student flow for all three conditions will be covered in a subsequent section.

The second independent variable was simulator platform motion. There were two levels of this variable: level one used the full six-degree-of-freedom platform motion available; for level two the platform was stationary.

The third independent variable consisted of the weapons delivery tasks performed by the study subjects. Three different weapons delivery tasks were selected: the high drag 10-degree dive angle; the high drag 15-degree dive angle; and the 30-degree-angle dive bomb. Specific delivery parameters are described in Appendix A.

The final independent variable, initial flying ability, was chosen to give greater experimental control and to permit group comparisons on the effects of simulator training as a function of student ability. As stated above, the subjects were rank-ordered by the training squadron at Holloman AFB on the flying ability they demonstrated during lead-in training. This served two purposes: first, it allowed counterbalancing of subjects so that there were matched groups in the three training conditions; second, it made possible comparisons on the value of simulator training between students judged to have greater, as contrasted to lesser, initial flying ability.

Study Design

The design used throughout the study was an elementary two-factor "mixed" analysis of variance classified by Lindquist (1953) as a Type I design. The basic design lent itself nicely to the analysis requirements because for two level contrasts (i.e., motion versus no-motion, superior versus inferior students), it conveniently collapses in simpler paradigms. The three weapons delivery tasks (i.e., 10-degree, 15-degree, and 30-degree dive angles) comprised one factor of this design, while group-associated independent variables (i.e., conditions of training, simulator motion configurations, and initial flying ability) constituted the other.

The design was used for the many univariate analyses of variance performed on the data as well as the two multivariate cases.

Dependent Variables

There were three primary sets of dependent variables used in the study, and two of these sets were dichotomous.

Aircraft Performance Dependent Variables. Two classes of dependent measures resulted directly from student performance data obtained during the F-5B criterion flights. The first of these, bomb delivery accuracy, were scores from practice bombs dropped on the conventional gunnery range at Gila Bend, Arizona. The second dependent variable based on flying performance was instructor pilot ratings. Instructor pilots flying with the students in the aircraft gave subjective ratings on a scale of 0 to 4 on each bomb delivery attempt, which were converted into standard scores (mean of 50, standard deviation of 10) for analytic purposes. These ratings covered overall flying performance in the bombing pattern, but excluded any consideration of the actual bomb score.

Simulator Performance Dependent Variables. Similar to the above, there were two classes of dependent measures that resulted from student performance in the ASPT. The first of these, bomb delivery circular error, is a measure comparable in every respect to the corresponding measure observed during the check rides. A scoring algorithm in the simulator computer captured all release parameters on each delivery and computed an impact distance from the target center.

Capabilities of the ASPT were also used to record simulated flight parameters at the moment of bomb release. Airspeed, altitude, G-load, heading and dive angle were printed out for each weapons delivery. These were the parameters utilized in the multivariate analyses of variance.

Subject Questionnaire. Questionnaires were completed by all students at the end of training. (A facsimile of the questionnaire is contained in Appendix B.)

Syllabus Development

The first step in the syllabus development was to determine the tasks to be flown. The results from project 2235 showed that all conventional weapon deliveries could be flown in the ASPT. These weapons deliveries could be classified into three general categories: forward firing (strafe), low-angle bombing, and high-angle bombing.

Before the aircraft to be used in performing the criterion tasks was selected, it was planned to choose one task from each category. However, when the F-5B became the weapons platform, strafe had to be eliminated from consideration because the F-5B does not have guns. Rockets could have been used, but simulation of that capability had not yet been developed on the ASPT. It was decided, therefore, to use two low-angle bombing events and one high-angle event. The two low-angle events selected were 10- and 15-degree simulated high drag deliveries.

The high angle event selected was the 30-degree dive bomb. The skills required for this event are somewhat different than for the low-angle deliveries. More reliance on in-cockpit instruments is necessary to meet required release parameters. Higher angle events such as 45 degree or 60 degree were eliminated from consideration because they were not performed in the F-5B aircraft as a part of the normal training course.

The next step in the syllabus development was to determine how the deliveries would be taught in the ASPT and how they would be performed in the aircraft. On a conventional gunnery range, if both high- and low-angle events are to be flown, the low-angle events are flown first. This is done for several reasons, but primarily for time and fuel considerations. Consequently, this low-to-high sequence was followed throughout the study.

A prototype syllabus was established and several experience pilots with no previous air-to-surface training were selected to conduct a pretest of the mission scenarios. These trial runs provided insight into the amount of time required to conduct the training, the optimum length of each sortie, and at the same time provided experience in console operations for the instructors who would be doing the actual training. After several minor changes were made to the syllabus, the course of instruction was administered to a new UPT graduate with flying experience similar to the actual subjects. No problems were encountered and the sequence and instructional techniques were finalized prior to arrival of the first class of subjects.

Subject Training

After their arrival at Williams AFB, all of the subjects were given two blocks of "ground school" training during the study. The first block was presented on the first morning and consisted of an introductory briefing, an overview of the study, and a short phase review of air-to-surface weapons delivery.

At this point, the control group was separated from the experimental groups and given their second block of training, an orientation to the F-5B. (A sample training schedule appears in Appendix C.) This block of training consisted of instruction on aircraft procedures and ended with a test on critical action emergency procedures which were required knowledge prior to flight. For these subjects, the remainder of the first day was spent on the flight line with time in the cockpit to familiarize them with armament procedures and switchology. These control subjects then flew their two data flights in the F-5B on the second and third days (one flight per day). The content of the flights are described as follows.

After receiving the first block ground school with the control group, the experimental groups then proceeded with their simulator training. They did not receive the second block on F-5B procedures until after the simulator training had been completed.

The simulator training started with a 20-minute sound/slide presentation that covered the normal and emergency procedures the subjects would need to know prior to operating any of the simulation equipment. A trained operator gave each subject an individual checkout on these procedures in the simulator cockpit before the subject's first mission. This operator remained on duty throughout the training periods to act as a safety observer.

A schedule of the simulator training is presented in Appendix D. The syllabus for this training was divided into eight, 1-hour sorties. A building block approach was followed throughout. On the first simulator mission, a short familiarization flight was provided prior to starting the actual weapons delivery training. During this time, the subjects experienced the control forces and trim changes that would occur over the airspeed ranges that were later flown. Characteristics of the simulator visual system were explained so the subjects were well-adapted to the outside-the-cockpit environment.

After the familiarization period, the simulator was initialized to the gunnery range for the start of the air-to-surface training. The events were taught in sequence starting with the 10-degree-dive-angle task. The delivery was introduced with a pre-recorded demonstration of the base leg and final approach portions of the pattern. (See Appendix A for diagrams of the complete patterns.) The student was then "reset" to the same starting point and allowed to practice what he had seen. This part-task approach was selected to take

advantage of the available advanced training features such as problem freeze, initialization/reset, and record/playback. After several trials, the student again viewed the prerecorded demonstration. This presentation was dynamic for all flight instruments, stick, rudder, and throttles, as well as the visual scene. The student then flew the part-task pattern again with his own performance recorded. When this was replayed, he had instant feedback which he could use to analyze his own errors. The instructor pilots used the problem freeze feature frequently to stop the sequence and to point out what the student should have been seeing and doing. Finally, the full pattern was demonstrated and taught in much the same manner as the part-task pattern.

The second and third missions introduced the 15- and 30-degree tasks using the same procedures. Reinforcement of previously learned patterns was accomplished at several points in the missions. The instructor pilots used mission guides in order to follow the sequence exactly on each sortie. Thus, each student in the experimental groups received the same number of repetitions on each of the three bomb delivery tasks.

For the first three missions simulated wind conditions were calm, but starting with the fourth mission, subjects received instruction and practice with many various wind directions and speeds.

Testing Procedures

Criterion performance tests were administered in the F-5B aircraft for all groups and in the ASPT for the two experimental groups.

F-5B Tests. Each subject flew two flights in the F-5B. The test profile was identical for both flights and consisted of a total of nine bombing patterns on each flight. The F-5B carries six practice bombs; so, with three tasks, this resulted in the delivery of two bombs per task per sortie. One extra pattern was flown on each task so a practice run could be flown prior to the two actual weapons deliveries.

Simulator Tests. The last two sorties in the simulator were designed to give the subject the same profiles on the simulated range that he would fly on his two aircraft sorties. Each delivery was graded using the same weapons delivery criterion measure used on the aircraft data flights and instruction was minimal. For the scored portions of these flights, the winds were set to represent conditions typical of the Gila Bend Gunnery Range.

Scoring Procedures

Although the same general approach was used, real-world occurrences naturally beyond experimental control made it necessary to use slightly different scoring procedures for the aircraft criterion missions as opposed to the simulator criterion missions.

F-5B Tests. Ordnance dropped on the Gila Bend Gunnery Range was scored by observers positioned in towers near the bombing target. Upon impact, a small powder charge in each practice bomb discharged a puff of white smoke which was easily visible. Observers in the two towers used sighting transits to triangulate the location of the bomb impact. The triangulation readings were used to compute the distance of the impact from the center of the target. These circular error scores were relayed via radio to the aircraft after each event. Maximum distance for determining circular error was 300 feet, with anything outside this limit being reported as unscorable. These bombs were arbitrarily assigned a score of 301 feet for purposes of analysis.

Occasionally a malfunction prevented a bomb from releasing from the aircraft. These "no release" passes were rated by the instructor pilots since the pattern was flown but no bomb score was recorded. This was reflected in the analysis with some subjects having fewer total opportunities which were adjusted for mathematically. Of the total of eight malfunctions that occurred, there were seven in the Control Group, and one in the Motion Experimental Group.

Simulator Tests. The simulator had a theoretically unlimited number of bombs. Each time the pilot released a simulated bomb, the instructor received a graphical display of the bomb impact on a cathode-ray tube which depicted the target circle. He also received a printout of the exact parameters so he could analyze and critique the subjects' performance. Since the computer was scoring the bombs, there were none recorded "unscorable." No release malfunctions occurred during the simulator training.

III. RESULTS

The research performed in this study addressed three objectives which may be simplified into the following questions:

1. Does simulator training improve air-to-surface weapons delivery skills in novice pilots?

2. Does simulator platform motion contribute to any degree to such training?

3. Does a fixed amount of simulator training affect novice pilots of higher versus lower ability levels to the same extent?

The hypotheses tested in the analyses of results were taken directly from these questions. (The source tables for these analyses are given in Appendix E.) Accordingly, this section is organized to answer these questions in the order in which they appear.

The remaining dependent variable set, subject questionnaire responses, is separately analyzed at the end of the section. Because these data consisted of subjective opinions, a quantitative analysis was not possible, but where substantial response concurrence occurred, it is identified and reported.

Simulator Training Effects

The analysis of the ASPT training effects was based on a series of contrasts between the Control Group (C) and the Experimental Groups (E_1 and E_2). The data collected made possible four comparisons. The dependent variables used for these comparisons were: number of gunnery range qualifying bombs; number of gunnery range scorable bombs, gunnery range bomb circular error; and, instructor pilot ratings on F-5B flying performance.

Number of Qualifying Bombs. A Chi-Square was performed to test for significant differences in the number of qualifying bomb deliveries made by the C and E groups. Using TAC criteria, qualification was defined as a circular error of 105 feet, or less, for 10-degree and 15-degree dive angles and 140 feet, or less, for the 30-degree dive angle. Both E groups were found to be significantly better than the C group at the five percent level of confidence ($\chi^2 = 6.99$). Table 1 lists the observed values and percentages for the three groups.

Table 1. **Number of Qualifying Bombs (Training Effects Analysis)**

	Qualifying		Misses	
	Number	Percentage	Number	Percentage
C	24	27	64	73
E_1	41	43	54	57
E_2	42	44	54	56

Number of Scorable Bombs. Similar to the first analysis, Chi-Square was used to test for significant differences in the number of scorable (circular error of 300 feet, or less) bombs delivered by the C and E groups. Again, the E groups were significantly better at the five percent level of confidence ($\chi^2 = 7.82$). Table 2 lists the observed values and percentages for the three groups.

Table 2. **Number of Scorable Bombs (Training Effects Analysis)**

	Scorable		Misses	
	Number	Percentage	Number	Percentage
C	64	72	25	28
E_1	82	86	13	14
E_2	82	85	14	15

Bomb Delivery Circular Error. Using the circular error on bomb delivery tasks in the F-5B aircraft as the dependent variable, a Lindquist Type I analysis of variance was conducted to compare the C and E groups. The overall F value was significant at the five percent level of confidence ($F = 4.39$) and a Tukey Multiple Comparison Test proved both E groups to be superior to the C group at the same level of confidence. There were no significant differences between the E_1 and E_2 groups. Table 3 lists the observed means for each group on the three bomb delivery tasks.

Table 3. **Bomb Delivery Circular Error Means (Training Effects Analysis)**

	10° dive angle	15° dive angle	30° dive angle
C	200'	180'	204'
E_1	148'	138'	169'
E_2	138'	144'	159'

Flying Performance Ratings. The same Lindquist Type I design was employed to analyze differences between the C and E groups where the dependent measure was instructor pilot rating of F-5B flying performance. Although the E groups' ratings were superior to those assigned the C group at the 20 percent level of confidence, the F value was not significant at the five percent level ($F = 2.36$). Table 4 lists the mean ratings received by each group on the three bomb delivery tasks.

Table 4. **Flying Performance Rating Means (Training Effects Analysis)**

	10° dive angle	15° dive angle	30° dive angle
C	44.6	48.9	49.4
E_1	52.7	52.7	48.3
E_2	49.4	52.2	51.1

Platform Motion Effects

Considerable effort was expended on the analyses of possible simulator platform motion effects. The results may be summarized at the outset by stating that none were found. However, since the issue is an important one for device configuration, the lack of significant differences and the extreme closeness of the two experimental groups on the dependent measures were of interest.

In addition to the dependent variables previously used for C and E group contrasts, the simulator data were also available for analysis. The approach taken followed this pattern, analyzing F-5B data first and simulator data second.

F-5B Data: Number of Qualifying Bombs. A Chi-Square Test performed on the data given in Table 1 found no significant differences between the E_1 and E_2 groups (χ^2 = .01). In fact, when the hung bomb on one task is considered, the scores of the two groups are identical.

F-5B Data: Number of Scorable Bombs. A Chi-Square Test performed on the data given in Table 1 also showed no differences between the E_1 and E_2 groups (χ^2 = .03). Again, allowing for the hung bomb in the E_1 group, the numbers are identical.

F-5B Data: Bomb Delivery Circular Error. The Lindquist Type I analysis of variance resulted in no significant differences (F = .06) between the means of the two experimental groups (see Table 3).

F-5B Data: Instructor Pilot Ratings of Flying Performance. As before, the analysis of variance produced no significant differences (F = .03) between the mean of the E_1 and E_2 groups (see Table 4).

The analysis of the simulator training data for the motion and no-motion experimental groups also failed to yield significant differences. Four analyses were run on this data. The first analysis used bomb delivery circular error as the dependent variable and was performed to determine if there was an initial difference between the two groups. The second analysis used the same dependent variable and was conducted to see if the groups differed at the conclusion of their simulator training. The third and fourth analyses paralleled these initial and final comparisons but used aircraft delivery parameters (airspeed, heading, release altitude, G-load, and dive angle) as the dependent variables in a multivariate analysis of variance.

Initial Bomb Delivery Circular Error. A Lindquist Type I analysis of variance was performed on the observed average bomb delivery circular error recorded for each subject on his initial six attempts on each task (i.e., 10-, 15-, and 30-degree dive angles). The results showed no significant difference at the five percent level of confidence (F = .61). Table 5 lists the observed means for each group on the three bomb delivery tasks.

Table 5. **Initial Bomb Delivery Circular Error Means (Motion Effects Analysis)**

	10° dive angle	15° dive angle	30° dive angle
E_1	189'	175'	151'
E_2	151'	126'	159'

Final Bomb Delivery Circular Error. The same procedure was used to determine if the E_1 and E_2 groups' final performance (eighth simulator mission) on these tasks differed significantly. At the five percent level of confidence this was found not to be the case (F = .00). Table 6 lists the observed means for each group on the three bomb delivery tasks.

Table 6. **Final Bomb Delivery Circular Error Means (Motion Effects Analysis)**

	10° dive angle	15° dive angle	30° dive angle
E_1	107'	104'	129'
E_2	121'	86'	133'

Initial Aircraft Delivery Parameters. The basic "groups by tasks" design was employed for the multivariate analysis of variance performed on aircraft delivery parameters observed for the initial three simulator missions. Unlike the univariate cases, there were *five* dependent variables analyzed simultaneously. Rao's approximation of the F-distribution provided the test of significance (Tatsuoka, 1971). The result was an R-value of .28 which is not significant at the five percent level of

confidence. The observed mean differences from the ideal value for each aircraft parameter are given in Table 7 for each experimental group and task.

Table 7. **Initial Aircraft Delivery Parameters (Motion Effects Analysis)**

	10° dive angle		15° dive angle		30° dive angle	
E_1	Heading	1.57°	Heading	2.52°	Heading	4.65°
	Altitude	85.04′	Altitude	55.10′	Altitude	152.09′
	Airspeed	5.63 kts	Airspeed	5.95 kts	Airspeed	6.06 kts
	G-Load	.18g	G-load	.22g	G-load	.31g
	Dive Angle	1.39°	Dive Angle	1.05°	Dive Angle	1.46°
E_2	Heading	1.50°	Heading	1.66°	Heading	3.20°
	Altitude	110.01′	Altitude	67.08′	Altitude	111.50′
	Airspeed	4.51 kts	Airspeed	7.55 kts	Airspeed	5.11 kts
	G-load	.14g	G-load	.18g	G-load	.33g
	Dive Angle	1.63°	Dive Angle	.83°	Dive Angle	1.12°

Final Aircraft Delivery Parameters. The analysis of the aircraft delivery parameters observed on the eighth simulator mission was identical to that used above. As before, the test for significant differences was Rao's approximation of the F-distribution, and the result was an R-value of 1.63. This was not significant at the five percent level of confidence. The observed mean differences from the ideal value for each aircraft parameter are listed in Table 8 for each experimental group and task.

Table 8. **Final Aircraft Delivery Paramters (Motion Effects Analysis)**

	10° dive angle		15° dive angle		30° dive angle	
E_1	Heading	1.39°	Heading	1.85°	Heading	3.21°
	Altitude	82.61′	Altitude	98.71′	Altitude	117.57′
	Airspeed	3.37 kts	Airspeed	4.24 kts	Airspeed	7.16 kts
	G-load	.19g	G-load	.19g	G-load	.25g
	Dive Angle	2.02°	Dive Angle	.97°	Dive Angle	1.05°
E_2	Heading	1.18°	Heading	1.40°	Heading	4.44°
	Altitude	95.99′	Altitude	73.11′	Altitude	216.48′
	Airspeed	3.73 kts	Airspeed	8.00 kts	Airspeed	4.42 kts
	G-load	.07g	G-load	.15g	G-load	.26g
	Dive Angle	2.64°	Dive Angle	1.09°	Dive Angle	1.63°

Subject Ability Levels and Simulator Training

It seemed reasonable to hypothesize that training in the ASPT would improve air-to-surface weapons delivery skills, but an interesting corollary question is: Who profits most? Is such simulator training more advantageous for the novice pilot of superior ability or for the novice pilot of inferior ability? Eight analyses were performed to answer this question. The first four of these analyses were based on data collected in the simulator; the second four used data collected during the aircraft sorties.

Simulator Data. Using the Lindquist Type I design, four univariate analyses of variance were conducted to determine whether ASPT training was more beneficial to the subjects rated as the upper one-half or the lower one-half of the class

from lead-in training. For all of these analyses, bomb delivery circular error served as the dependent variable.

The first analysis investigated the initial disparity in weapons delivery skills between the upper one-half and lower one-half groups. It was rather surprising to find that the groups did not differ significantly at the five percent level of confidence (F = .58). Table 9 gives the initial attempts observed means for each group on the three bomb delivery tasks studied.

Table 9. **Initial Bomb Delivery Circular Error Means (Student Ability Analysis)**

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	178′	114′	152′
Lower 1/2	174′	187′	158′

At the conclusion of the simulator training, however, there was a definite difference in degree of skill shown by the two groups. The F-value equaled 3.14 and was significant at the five percent level of confidence with a directional hypothesis. Table 10 gives the final attempt observed means for each group on the three bomb delivery tasks.

Table 10. **Final Bomb Delivery Circular Error Means (Student Ability Analysis)**

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	86′	96′	110′
Lower 1/2	132′	94′	153′

The percentage of improvement demonstrated in each task was computed for the two groups. Table 11 presents these data. The "average" improvement was 30 percent for the upper one-half group and 26 percent for the lower one-half group.

Table 11. **Percent Improvement in Bomb Delivery Circular Error (Student Ability Analysis)**

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	46%	16%	28%
Lower 1/2	24%	50%	3%

To see if the improvement shown by the upper one-half group was significant, Lindquist Type I analysis of variance was performed on the initial, as contrasted to the final, circular error scores. The resulting F-value of 13.15 was significant at the five percent level of confidence. When the same analysis was run on the lower one-half group, the F-value was not significant at the five percent level (F = 1.95).

Aircraft Data. Four analyses on upper one-half versus lower one-half subjects were run using the data from the F-5B sorties as the dependent variables. The first analysis was a Chi-Square Test on the number of qualifying bombs delivered by the two groups. The resulting Chi-Square value of 1.57 was not significant at the five percent level of confidence (Table 12).

Table 12. **Number of Qualifying Bombs (Student Ability Analysis)**

	Qualifying		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	46	48	50	52
Lower 1/2	37	39	58	61

The second analysis was essentially a repeat of the first, except that number of scorable bombs was used as the dependent variable. Again, the Chi-Square Test was not significant at the five percent level (χ^2 = 1.16). Table 13 gives the observed values and percentages for the two groups.

Table 13. **Number of Scorable Bombs (Student Ability Analysis)**

	Scorable		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	85	88	11	12
Lower 1/2	79	83	16	17

When bomb delivery circular error was used as the dependent variable, the Lindquist Type I analysis of variance resulted in an F-value of .73 which was not significant at the five percent level of confidence. Table 14 gives the means for each group on the three bomb delivery tasks.

Table 14. **Bomb Delivery Circular Error Means (Student Ability Analysis)**

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	119′	162′	143′
Lower 1/2	154′	133′	184′

The same design was used to evaluate instructor pilot ratings of F-5B flying performance for the two groups. The resulting F-value of 1.22 was not significant at the five percent level of confidence. Table 15 lists the means ratings received by each group on the three bomb delivery tasks.

Table 15. **Flying Performance Rating Means (Student Ability Analysis)**

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	52.7	51.1	52.7
Lower 1/2	49.4	53.8	46.7

The end result of these four analyses was that although none individually reached the five percent level of confidence, when viewed collectively, they offered strong evidence that it was the superior students who gained most from the simulator training. The outcomes of all four analyses were in the same direction. When the actual probability levels of the Chi-Square and F-Test were taken into consideration, the level of confidence reached was far beyond the five percent point.

Questionnaire Analysis

The open-ended questionnaires were naturally not amenable to quantitative analysis but did provide a valuable source for insights into the subjects' attitudes and opinions about the program. Although the feelings expressed by the subjects were sometimes diametrically opposed to one another, there was considerable consensus as to the program components on which comments were made. This result was interpreted as the significant findings revealed by the questionnaire. The statements listed below comprised the essence of the point (or counterpoint) reported by 25 percent, or more, of the subjects.

1. "In general, it was a good program and the training was highly beneficial." This opinion was expressed by nearly all subjects. None reported negative feelings.

2. "The objectives of the program were well explained." Subject opinion was unanimous on this point.

3. "The orientation to the F-5B was sparse." Many subjects believed they could have performed better on the gunnery range if there had been more time to fly and become familiar with the F-5B. This is most probably true, but study constraints could not allow additional sorties.

4. "More would have been learned if the simulator sortie were 1.5 hours in duration rather than 1 hour." Of the subjects who addressed this point, one-half favored the longer training session, but the other half desired *shorter* sessions with interspersed breaks.

5. "Two F-5B rides were not enough to demonstrate what was actually learned in ASPT." Due to the different flight characteristics between the ASPT and the F-5B, some subjects believed their gunnery range performance was degraded because they had not fully readjusted to the aircraft.

6. "The flight characteristics of ASPT should more closely resemble those of the F-5B." This comment is merely a restatement of the previous point.

7. "There should be more simulator rides with higher winds." This desire for more simulator training reflects favorably upon the perceived value of the program.

8. "The sight picture should be emphasized in the simulator training." This observation should be implemented in future ASPT research applications.

IV. DISCUSSION

Because the study was so basic, its methodology so in conformance with typical Air Force training operations and the results so clearcut, there is little to be added to that already presented. Therefore, this section will consist of only a few brief statements summarizing the effects of generalized air-to-surface simulator weapons training, simulator platform motion, and student ability as a variable in simulator training.

Simulator Training

The answer to the question, "Does generalized air-to-surface simulator weapons delivery training transfer to a specific aircraft?" is an unqualified "yes." Perhaps the most important aspect of this result, in terms of its implications for simulator and training program design, is the fact that the ASPT was configured as a T-37 (with a sighting device) and still there was significant tranfer of training to the F-5B. Although the finding that a low fidelity device can provide considerable training when properly employed is not new

(Prophet & Boyd, 1970), the study was a rather striking confirmation of the point.

There is little doubt that the training given by the program was highly beneficial to the novice pilots who served as subjects. Both the control and experimental groups gained valuable experience in air-to-surface weapons delivery with the experimental groups receiving the most.

Platform Motion

It is impossible to prove the null hypothesis, but the results of the study show unequivocally that six-degree-of-freedom platform motion did not enhance the training value of the simulator. Considering the aerial weapons delivery task, this is not a surprising finding. The task is primarily visual, and motion (or movement) serves only as an alerting stimulus to the pilot.

The fact has significant ramifications for simulator design. The deletion of platform motion requirements for air-to-surface simulation would have enormous cost-avoidance consequences. It is believed that a G-seat and G-suit (with appropriate stick and pedal "shakers") would provide all necessary "motion" cues needed for this simulation

Student Ability

In this study, it was the better novice pilot who profited the most from the ASPT training. In respect to their demonstrated weapons delivery skills, the upper one-half and lower one-half groups of student started statistically equal. At the conclusion of the simulator training, however, the upper one-half had made significant improvement (at the five percent level of confidence) from its starting point. Although the average performance of the lower one-half had also improved, it was not significant at this level of confidence.

The fact that the better student usually profits more when given fixed amounts of practice and receives the greatest benefits from innovations in training and education is a fairly common observation. The same general finding also occurs even when the content of the training program syllabus remains constant, but new media are introduced to convey this subject matter. That the present study was no exception to this general rule adds face validity to the results obtained.

V. PERSPECTIVE

The study was performed to answer three questions dealing with the role and effects of simulation when applied to training the acquisition of air-to-surface weapons delivery skills in novice pilots. Further, in order to produce results of strong generalization, the study was conducted in a manner that was completely realistic from an operational viewpoint.

Although only 24 individuals were used as subjects (eight each in a control and two experimental groups), the treatment effects were so powerful that clear-cut results emerged. Consequently, the findings of the study may be briefly summarized in the following three statements:

1. Conventional air-to-surface weapons delivery training, as accomplished using low-fidelity simulation, has significant transfer to a specific aircraft.

2. Six-degree-of-freedom platform motion does not contribute to this highly effective training.

3. Novice student pilots of greater (as contrasted to lesser) initial ability benefit most from such simulator training when a minimum fixed number of trials is used.

Bergeron, H.P. Investigation of motion requirements in compensatory control tasks. *IEEE Transactions on Man Machine Systems*, June 1970, MMS-11(2), 123-125.

Borlace, F. Flight simulator motion, its enhancement and potential for flight crew training. *Proceeding of the Third International Simulation and Training Conference*, New York: 27 April 1967.

Brown, F.P., Johnson, H.I., & Mungall, R.G. *Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task.* NASA-TN-D-367, AD-236 265, May 1960.

Caro, Paul W. *Equipment-device task commonality analysis and transfer of training.* HumRRO Technical Report 70-7, June 1970.

Demaree, R.G., Norman, D.A., & Matheny, W.G. *Experimental program for relation transfer of training to pilot performance and degree of simulation.* NAVTRADEVCEN-TR-1388-1. Naval Training Device Center, June 1965.

Hagin, W.V., & Smith, J.F. *Advanced simulation in undergraduate pilot training (ASUPT) facility utilization plan.* AFHRL-TR-74-43, AD-786 411. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, June 1974.

Huddleston, H.F. *Cockpit motion requirements for flight simulation.* Royal Air Force Institute of Aviation Medicine, Farnborough, Hants, January 1966.

Hutton, D.P., Burke, D.K., Englehard, J.D., Wilson, J.M., Rumaglia, F.J., & Schneider, A.J. *Air-to-ground visual simulation demonstration.* (2 vols.). Aeronautical Systems Division, Simulator SPO, Wright-Patterson AFB, OH: October 1976.

Irish, P.A., III., Grunzke, P.M., Gray, T.H., & Water, B.K. *The effects of system and environmental factors upon experienced pilot performance in the advanced simulator for pilot training* AFHRL-TR-77-13. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, April 1977.

Jacobs, R.S., & Roscoe, S.N. Simulator cockpit motion and the transfer of initial flight training. *Proceedings of the Eighth NTEC/Industry Conference*, November 1975.

Jacobs, R.S., Williges, R.C., & Roscoe, S.N. Simulation motion as a factor in flight-director display evaluation. *Human Factors*, December 1973, **15**(6), 569-582.

Koonce, J.M. *Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency.* AFOSR 74-3. Air Force Office of Scientific Research, Illinois University, April 1974.

Lindquist, E.F. *Design and analysis of experiments in psychology and education.* Boston. Houghton Mifflin Company, 1953.

Prophet, W.W., & Boyd, H.A. *Device-task fidelity and transfer of training: aircraft cockpit procedures training.* HumRRO Technical Report 70-10, July 1970.

Prophet, W.W., Caro, P.W., & Hall, E.R. *Some current issues in the design of flight training devices.* HumRRO Professional Paper 5-72. March 1972.

Rathert, G.A., Creer, B.Y., & Sadoff, M. *The use of piloted flight simulators in general research.* Report 365. NATO Advisory Group for Aeronautical Research and Development, 1961.

Reid, G.B., & Cyrus, M.L. *Tranfer of training with formation flight trainer.* AFHRL-TR-74-102, AD-A009 638. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, December 1974.

Rust, S.K. Flight simulator fidelity assurance. *Proceedings of the Eighth NTEC/Industry Conference*, November 1975.

Tatsuoka, M.M. *Multivariate analysis: techniques for educational and psychological research.* New York: John Wiley and Sons, Inc., 1971.

Woodruff, R.R., & Smith, J.F. *T-4G simulator and T-4 ground training devices in USAF undergraduate pilot training.* AFHRL-TR-74-78, AD-A008 197. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, November 1974.

BIBLIOGRAPHY

Dunlap, D.S., & Worthey, R.E. *Air Force master plan simulators for aircrew training.* ASD/XR, TR-75-18. Andrews AFB, MD: September 1975.

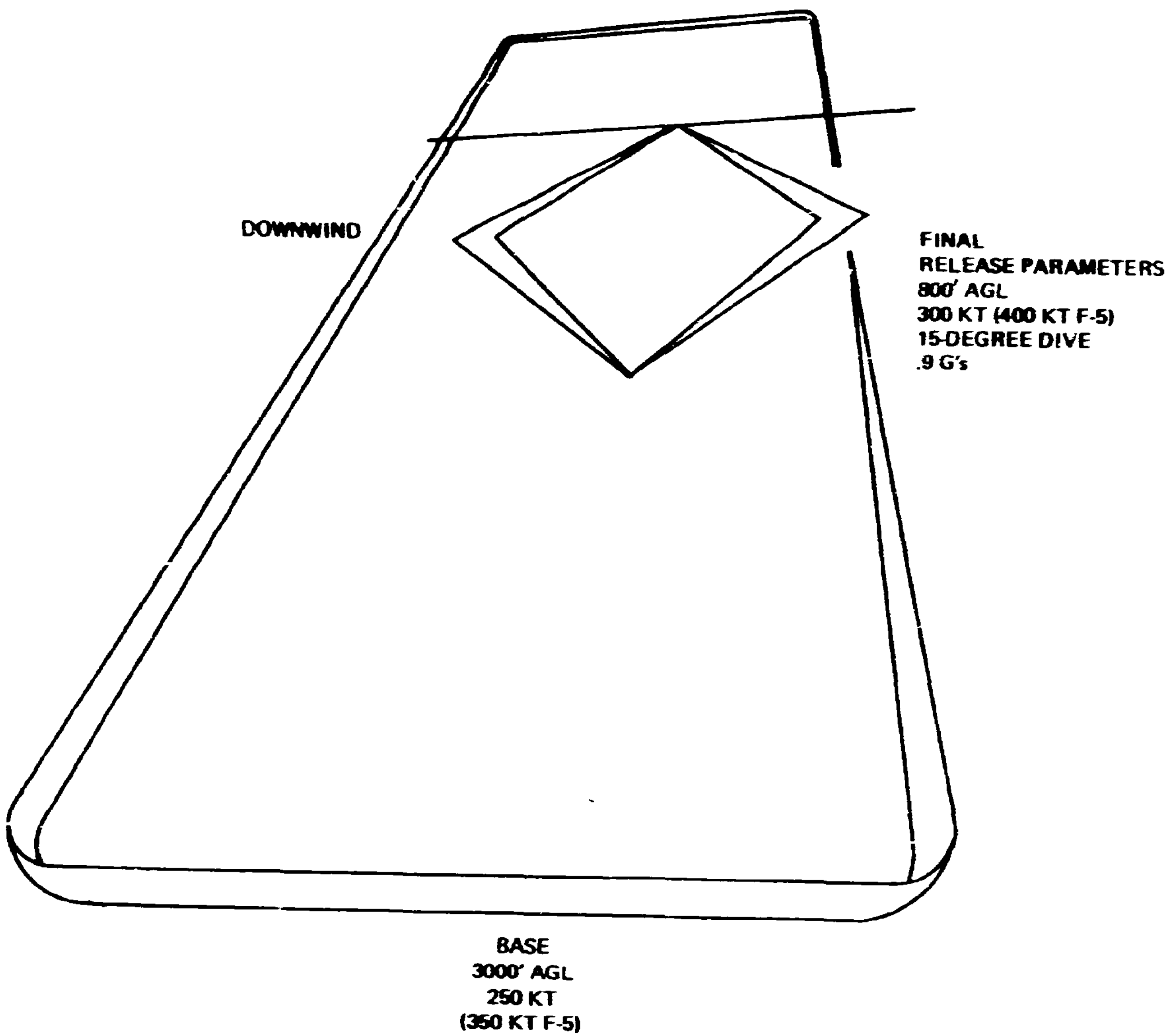
Gundry, A.J. *The role of motion in flight simulator training: an alternative interpretation of some recent evidence.* IAM Scientific Memorandum No. 123. Royal Air Force Institute of Aviation Medicine, 1976.

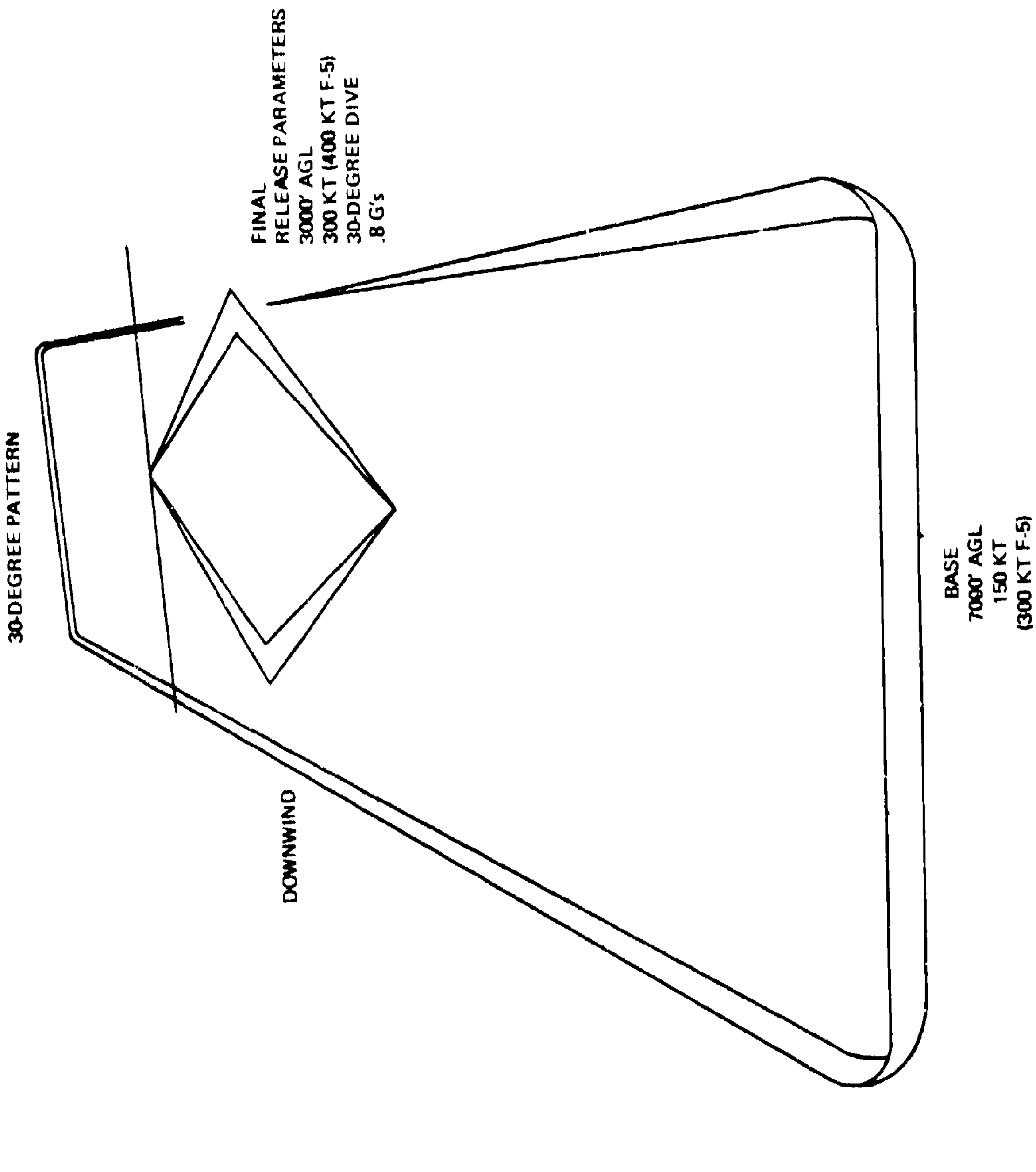
Taylor, R., Gerber, A., Allen, M., Brown, L., Cohen, E., Dunbar, D., Flexman, R., Hewit, W., McElwain, D., Pancoe, E., & Simpson, D. *Study to determine requirements for undergraduate pilot training research simulation system (UPTRSS).* AFHRL-TR-68-11, AD-858-640. Wright-Patterson AFB, OH: Training Research Division, Air Force Human Resources Laboratory, July 1969.

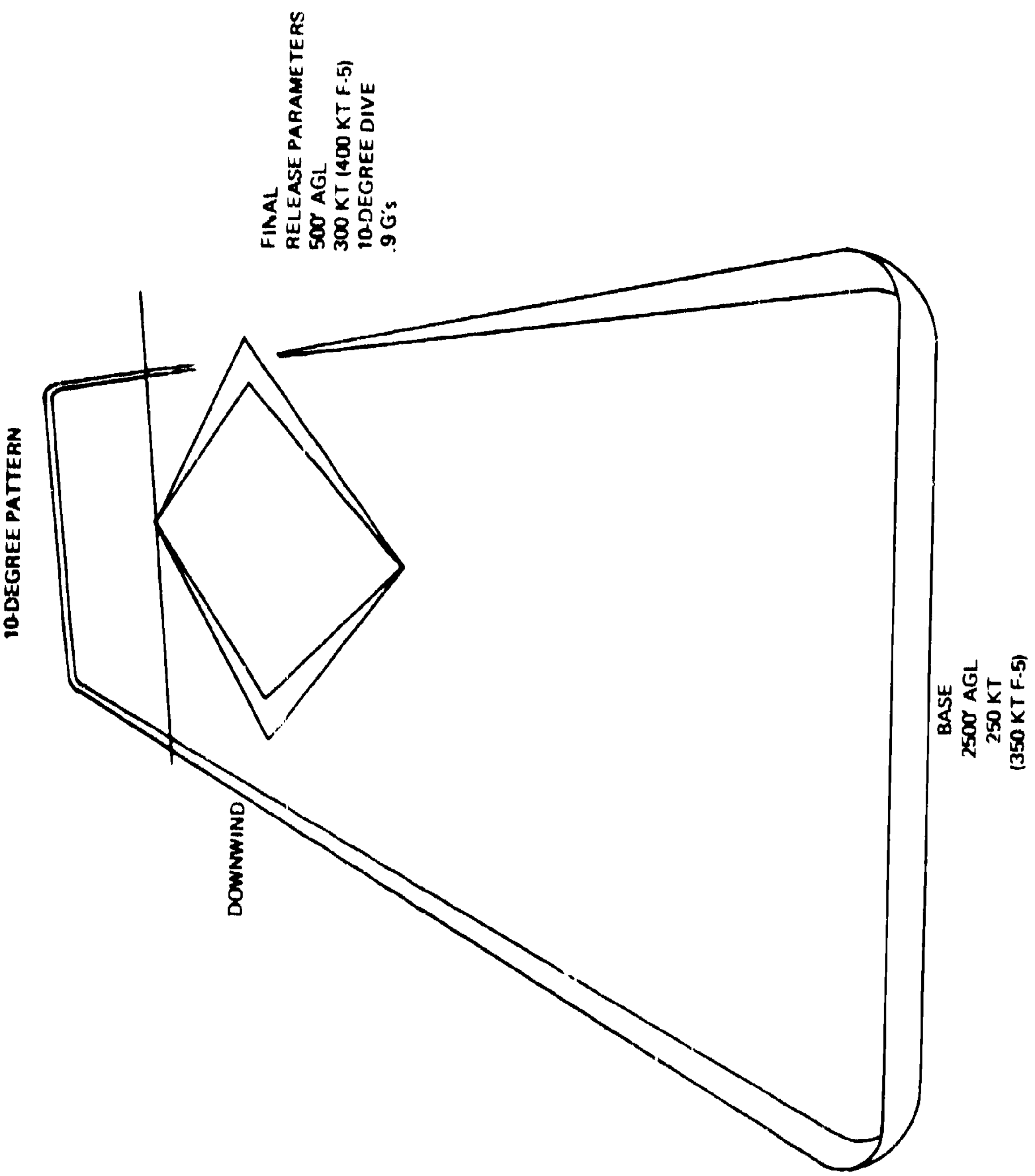
Valverde, H.H. *Flight simulators–a review of the research and development.* AMRL-TR-68-97, AD-855 582. Wright-Patterson AFB, OH: July 1968.

APPENDIX A: BOMB DELIVERY PARAMETERS AND TASK PATTERNS

15-DEGREE PATTERN




30-DEGREE PATTERN
FINAL
RELEASE PARAMETERS
3000' AGL
300 KT (400 KT F-5)
30-DEGREE DIVE
.8 G's
DOWNWIND
BASE
7000' AGL
150 KT
(300 KT F-5)


10-DEGREE PATTERN
FINAL
RELEASE PARAMETERS
500' AGL
300 KT (400 KT F-5)
10-DEGREE DIVE
.9 G's
DOWNWIND
BASE
2500' AGL
250 KT
(350 KT F-5)

APPENDIX B: STUDENT QUESTIONNAIRES

NAME: ____________________ ID NUMBER: ____________________

DATE: ____________________ GROUP: ____________________

1. Total number of flight hours: ____________

   a. A/C type: ____________ flight hours: ____________

   b. ____________ ____________

   c. ____________ ____________

   d. ____________ ____________

2. Total number of simulator training hours: ____________

   a. Simulator type: ____________ training hours: ____________

   b. ____________ ____________

   c. ____________ ____________

2a. Were the training objectives of this special program clear to you:

____

____

b. What, if anything, was not clear? ____________________

____

____

3a. Was the instruction well managed and presented? ____________

____

____

b. If not, what areas would you change? ____________________

____

____

4a. Were there areas of instruction you felt were incomplete? ____________

____

____

b. If so, what were they? ______________________________

____

____

____

5a. Would you add anything to this special program? ____________

b. If so, what? ____________________________________

____

____

____

APPENDIX C: MANAGEMENT TRAINING SCHEDULE

MANAGEMENT SCHEDULE

Academics	Training Days						
	1	2	3	4	5	6	7
Control Group	1,2					2	
Experimental Groups	1						
Simulator Sorties							
Experimental Groups		1,2	3,4	5,6	7,8		
Aircraft Sorties							
Control Group		1	2				
Experimental Groups						1	2

CONTROL GROUP

	MONDAY		TUESDAY	WEDNESDAY
0900	Bldg 558 Conf Rm	0600	Pilot 1 GA1 IP 1	Pilot 2 GA2 IP 1
1000	GA Review		Pilot 2 GA1 IP 2	Pilot 1 GA2 IP 2
1100	Hospital Flt Surg			
1200	Lunch			
1300	F-5 Brief Bldg 42			
	IP 1 Capt Seymour IP 2 Capt Hukee		Pilot 1 Hargarten Pilot 2 Hamilton	

Air-to-Ground Experimental Groups Schedule

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
0600						
0700			Pilot 2 GA3 IP 1			
0800		Pilot 1 GA1 IP 1	Pilot 3 GA3 IP 1 (0815)	Pilot 3 GA5 IP 1	Pilot 4 GA7 IP 2	
0900	Bldg 558 Conf Rm	Pilot 2 GA 1 IP 1	Pilot 4 GA3 IP 1 (0930)	Pilot 4 GA5 IP 1	Pilot 1 GA7 IP 2	
1000	GA Review	Pilot 3 GA1 IP 1		Pilot 1 GA5 IP 2	Pilot 2 GA7 IP 1	
1100	Hospital Flt Surg	Pilot 4 GA1 IP 1	Pilot 1 GA3 IP 1 (1045)	Pilot 2 GA5 IP 2	Pilot 3 GA7 IP 1	
1200	Lunch					
1300	Bldg 558 Conf Rm	Pilot 1 GA2 IP 2	Pilot 2 GA4 IP 2	Pilot 3 GA6 IP 1	Pilot 4 GA8 IP 2	
1400		Pilot 2 GA2 IP 2	Pilot 3 GA4 IP 2	Pilot 4 GA6 IP 1	Pilot 1 GA8 IP 2	
1500		Pilot 3 GA2 IP 2	Pilot 4 GA4 IP 2	Pilot 1 GA6 IP 2	Pilot 2 GA8 IP 1	
1600		Pilot 4 GA2 IP 2	Pilot 1 GA4 IP 2	Pilot 2 GA6 IP 2	Pilot 3 GA8 IP 1	
1700						
1800						
1900						
2000						

IP 1 Capt Henrich
IP 2 Capt Seymour

Pilot 1 Gunther
Pilot 2 Wallace
Pilot 3 Schmitt
Pilot 4 Rayburn

APPENDIX D: SIMULATOR TRAINING SCHEDULE

ASUPT GA1

NAME: ________________ DATE: ________________

IP NAME: ______________ TIME: ________________

FAMILIARIZATION/10° HIGH DRAG

	INIT 005	1	Free flight - acro, trim checks 100 knots to 300 knots
15 min			
	Demo	1	Part task 10 deg
	Reset	4	Part task 10 deg ____ ____ ____ ____
	Demo	1	Part task 10 deg
	Reset	1	Part task - Record ____
		1	Playback
30	Reset	2	Part task 10 deg ____ ____
	Demo	1	Full pattern 10 deg
	Reset	6	Full pattern 10 deg (Repeat Demo once.) (One Record/Playback.) ____ ____ ____
50			____ ____ ____

ASUPT GA2

NAME: ____________________ DATE: ____________________

IP NAME: _________________ TIME: ____________________

15° HIGH DRAG

	INIT 093	1	Part task 10 deg _____
	Continue	5	Full pattern 10 deg
10			_____ _____ _____ _____ __ __
	Demo	1	Part task 15 deg
	Reset	4	Part task 15 deg _____ _____ _____ _____
	Demo	1	Part task 15 deg
	Reset	1	Part task - Record _____
		1	Playback
20	Reset	2	Part task 15 deg _____ _____
	Demo	1	Full pattern 15 deg
	Reset	6	Full pattern 15 deg (Repeat Demo once.) (One Record/Playback.)
			_____ _____ _____
40			_____ _____ _____
	Init 091	2	Full pattern 10 deg _____ _____
50	Continue	2	Full pattern 15 deg _____ _____

ASUPT GA3

NAME: ____________________ DATE: ____________________

IP NAME: ________________ TIME: ____________________

30^{0} DIVE

	INIT 091	2	Full pattern 10 deg _____ _____
_____ 10	Continue	4	Full pattern 15 deg
			_____ _____ _____ _____
	Demo	1	Part task 30 deg
	Reset	4	Part task 30 deg _____ _____ _____ _____
	Demo	1	Part task 30 deg
	Reset	1	Part task - Record _____
		1	Playback
_____ 30	Reset	2	Part task 30 deg _____ _____
	Demo	1	Full pattern 30 deg
		6	Full pattern 30 deg (Repeat Demo once.) (One Record/Playback.)
			_____ _____ _____
_____ 40			_____ _____ _____
	INIT 091	2	Full pattern 10 deg _____ _____
	Continue	2	Full pattern 15 deg _____ _____
_____ 50	Continue	2	Full pattern 30 deg _____ _____

ASUPT GA4

NAME: ____________________ DATE: ____________________

IP NAME: ____________________ TIME: ____________________

WIND ADJUSTMENTS

	INIT 091	2	Full pattern 10 deg	_____ _____
	Continue	2	Full pattern 15 deg	_____ _____
15 _____	Continue	4	Full pattern 30 deg	_____ _____
				_____ _____
	Demo	1	10 deg - 090/10	
	Reset	4	Full pattern 10 deg, 090/10	
			_____ _____ _____ _____	
		4	Full pattern 10 deg, 360/10	
			_____ _____ _____ _____	
		4	Full pattern 10 deg, 045/10	
40 _____			_____ _____ _____ _____	
		3	Full pattern, 15 deg, 090/10	_____ _____ _____
50 _____		3	Full pattern, 30 deg, 090/10	_____ _____ _____

ASUPT GA5

NAME: ____________________ DATE: ____________________

IP NAME: ____________________ TIME: ____________________

WIND ADJUSTMENTS

	INIT 091	2	Full pattern 10 deg 270/10 _____ _____
		2	Full pattern 15 deg 270/10 _____ _____
_____ 10		2	Full pattern 30 deg 270/10 _____ _____
		3	Full pattern 10 deg _____ _____ _____
		3	Full pattern 15 deg _____ _____ _____
_____ 30		3	Full pattern 30 deg _____ _____ _____
	INIT 093	2	Full pattern 10 deg 225/20 _____ _____
		2	Full pattern 15 deg 225/20 _____ _____
_____ 40		2	Full pattern 30 deg 225/20 _____ _____
	INIT 091	2	Full pattern 10 deg 315/10 _____ _____
		2	Full pattern 15 deg 315/10 _____ _____
_____ 50		2	Full pattern 30 deg 315/10 _____ _____

ASUPT -6

NAME: ____________________ DATE: ____________________

IP NAME: ________________ TIME: ____________________

WIND ADJUSTMENTS

INIT 091 3 15 deg no wind

____ ____ ____

3 30 deg no wind

____ ____ ____

____
15

INIT 091 3 10 deg 290/5

____ ____ ____

3 15 deg 290/5

____ ____ ____

3 30 deg 290/5

____ ____ ____

____
35

INIT 091 3 10 deg 110/15

____ ____ ____

3 15 deg 110/15

____ ____ ____

3 30 deg 110/15

____ ____ ____

____
50

ASUPT 7

NAME: ____________________ DATE: ____________________

IP NAME: _________________ TIME: ____________________

BOMBING FOR QUALIFICATION

	TEST INIT 091	1	10 deg (dry)	310/10
		2	10 deg	310/10
			_____ _____	
		1	15 deg (dry)	310/10
		2	15 deg	310/10
			_____ _____	
		1	30 deg (dry)	310/10
______ 15		2	30 deg	310/10
			_____ _____	
	Practice INIT 091	3	10 deg	135/25
			_____ _____	_____
		3	15 deg	135/25
			_____ _____	_____
		3	30 deg	135/25
______ 30			_____ _____	_____
	INIT 091	3	10 deg	045/5
			_____ _____	_____
		3	15 deg	060/12
			_____ _____	_____
		3	30 deg	090/15
______ 50			_____ _____	_____

ASUPT 8

NAME: ____________________ DATE: ____________________

IP NAME: ____________________ TIME: ____________________

BOMBING FOR QUALIFICATION

	TEST INIT 091	1	10 deg (dry)	030/8
		2	10 deg	030/8
			_____ _____	
		1	15 deg (dry)	030/8
		2	15 deg	030/8
			_____ _____	
		1	30 deg (dry)	030/8
		2	30 deg	030/8
_____ 15			_____ _____	
	Practice INIT 091	3	10 deg	110/10
			_____ _____ _____	
		3	15 deg	110/10
			_____ _____ _____	
		3	30 deg	110/10
_____ 30			_____ _____ _____	
	Test INIT 091	1	10 deg (dry)	240/10
		2	10 deg	240/10
			_____ _____	
		1	15 deg (dry)	240/10
		2	15 deg	240/10
			_____ _____	
		1	30 deg (dry)	240/10
		2	30 deg	240/10
_____ 50				

APPENDIX E: ANALYSIS OF VARIANCE SOURCE TABLES

Training Effects Analysis
Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	23	112893	4908	
B	2	33264	16632	4.39
error (b)	21	79629	3791	
Within-Subjects	48	134314	2798	
A	2	6537	3268	1.09
AB	4	1884	471	.16
error (w)	42	125892	2997	
Total	71	247208		

Training Effects Analysis
Flying Performance Rating
Source Table

Source	df	SS	MS	F-value
Between-Subjects	17	593	34	
B	2	141	70	2.36
error (b)	15	451	30	
Within-Subjects	36	1125	31	
A	2	54	27	.86
AB	4	132	33	1.06
error (w)	30	939	31	
Total	53	1718		

Motion Effects Analysis
Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	66277	4418	
B	1	261	261	.06
error (b)	14	66016	4715	
Within-Subjects	32	73287	2290	
A	2	5054	2527	1.05
AB	2	748	374	.16
error (w)	28	67485	2410	
Total	47	139565		

Motion Effects Analysis
Flying Performance Rating
Source Table

Source	df	SS	MS	F-value
Between-Subjects	11	401	36	
B	1	1	1	.03
error (b)	10	400	40	
Within-Subjects	24	716	29	
A	2	45	22	.74
AB	2	55	27	.89
error (w)	20	616	30	
Total	35	1118		

Motion Effects Analysis
Initial Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	196744	13116	
B	1	8342	8242	.61
error (b)	14	188502	13464	
Within-Subjects	32	203345	6354	
A	2	3159	1579	.23
AB	2	7443	3721	.54
error (w)	28	192742	6883	
Total	47	400089		

Motion Effects Analysis
Final Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	43853	2923	
B	1	.5	.5	.00
error (b)	14	43852	3132	
Within-Subjects	32	58274	1821	
A	2	10594	5297	3.26
AB	2	2237	1118	.69
error (w)	28	45442	1622	
Total	47	102127		

Motion Effects Analysis
Multivariate Analysis of Variance
Summary Table

Factor	SSCP	νh df	Λ-value	ν_e	m	s	$\frac{ms - \frac{p\nu h}{2} + 1}{p\nu h}$	$(p\nu h,\ ms - \frac{p\nu h}{2} + 1)$
B	$SSCP_B$	1	$SSCP_{\varepsilon(b)} 1/1SSCP_B + SSCP$	14	11.5	1	2	(5,10)
A	$SSCP_A$	2	$SSCP_{\varepsilon(w)} 1/1SSCP_A + SSCP$	28	36	2	6.8	(10,68)
AB	$SSCP_{AB}$	2	$SSCP_{\varepsilon(w)} 1/1SSCP_{AB} + SSCP$	28	36	2	6.8	(10,68)

Where P = 5, νe is the df of the SSCP matrix in the numerator of Λ, νh is the df of the SSCP matrix appeared in the first term of the denominator of Λ. $m = \nu e + \nu h - 1/2\,(p + \nu h + 1)$ and $s = \frac{(p\nu h)^2 - 4}{p^2 + \nu h^2 - 5}$

Rao's approximate F-distribution:

$$R = \frac{1 - \Lambda^{\frac{1}{s}}}{\Lambda^{\frac{1}{s}}} \; \frac{ms - \frac{p\nu h}{2} + 1}{p_{\nu h}} \sim F\left(p_{\nu h},\ ms - \frac{p\nu h}{2} + 1\right)$$

Initial Delivery Parameters

	Λ-value	R-value	P-value
B	.87862941	.27627254	$.9 < p < .95$
A	.11557055	13.20254783	$p < .0001$
AB	.62278399	1.81668454	$.05 < p < .10$

Motion Effects Analysis

Multivariate Analysis of Variance Summary Table
(cont)

Final Delivery Parameters

	Λ -value	R-value	P-value
B	.55169135	1.62521542	$.1<p<.25$
A	.22277257	7.60714911	$p<.0001$
AB	.46776974	3.14243705	$.001<p<.005$

A = Task

B = Groups

Student Ability Analysis
Initial Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	187840	12522	
B	1	7425	7425	.58
error (b)	14	180415	12886	
Within-Subjects	32	205345	6417	
A	2	5817	2908	.44
AB	2	14111	7055	1.07
error (w)	28	185416	6622	
Total	47	393185		

Student Ability Analysis
Final Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	43853	2923	
B	1	8034	80[illegible]	3.14
error (b)	14	35818	2558	
Within-Subjects	32	58274	1821	
A	2	10594	5297	3.45
AB	2	4725	2362	1.54
error (w)	28	42954	1534	
Total	47	102127		

Student Ability Analysis
Upper 1/2 Initial Versus Final Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	56202	3746	
B	1	27217	17217	13.15
error (b)	14	28984	2070	
Within-Subjects	32	65163	2036	
A	2	9206	4603	2.70
AB	2	8293	4146	2.44
error (w)	28	47664	1702	
Total	47	121366		

Student Ability Analysis
Lower 1/2 Initial Versus Final Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	213336	14222	
B	1	26086	26086	1.95,
error (b)	14	187249	13374	
Within-Subjects	32	198455	6201	
A	2	2023	1011	.16
AB	2	15726	7863	1.22
error (w)	28	180706	6453	
Total	47	411792		

Student Ability Analysis
Bomb Delivery Circular Error
Source Table

Source	df	SS	MS	F-value
Between-Subjects	15	58544	3902	
B	1	2914	2914	.73
error (b)	14	55630	3973	
Within-Subjects	32	78221	2444	
A	2	5966	2983	1.39
AB	2	12138	6069	2.83
error (w)	28	60116	2147	
Total	47	136765		

Student Ability Analysis
Flying Performance Rating
Source Table

Source	df	SS	MS	F-value
Between-Subjects	11	401	36	
B	1	43	43	1.22
error (b)	10	353	35	
Within-Subjects	24	716	29	
A	2	45	22	.83
AB	2	121	60	2.20
error (w)	20	550	27	
Total	35	1118		

★ U.S. GOVERNMENT PRINTING OFFICE: 1977 — 771-067/48